NATIONAL RADIO INSTITUTE

Certified Radio-Trician's Course

(REG. U. S. PAT. OFF.)

R. F. AMPLIFIER SYSTEMS

No. 20FR

Originators of Home Study Radio Courses
ESTABLISHED 1914
Washington, D. C.

FOREWORD

Did you get everything you could out of the previous lesson? If you didn't even though you were able to answer every question correctly, you may experience some difficulty with this lesson which is practically a continuation of the last one.

Do not overlook the value of review at any time. It is a good idea to keep completed lessons handy so that you can refer to them easily. Then again, you may often want to refer to certain diagrams for one reason or another. By studying diagrams a great deal can be learned.

At times when you find reading becoming tiresome, pick out a good, complete diagram and study it. Trace through all the circuits and review in your mind the actions of the various currents and the effects of the various parts. You will find this procedure a good means of relaxation and a method of review both interesting and instructive.

J. E. SMITH.

BF2M102830

Printed in U.S.A.

ANALYSIS OF R. F. AMPLIFICATION

A review of R.F. amplification will materially aid us in our study of radio frequency design.

Let us consider for purposes of review a single stage of tuned R.F. as in Fig. 1, the voltage through the aerial and ground system being supplied by a signal and equal to E_1. It is naturally very small, about 40 microvolts (40/1,000,000 of a volt). A current flows through primary L_1 and induces by mutual induction a voltage in the resonant circuit formed by L_2 and C_2. Should this circuit be tuned to the same frequency as the incoming signal a comparatively large current will flow, building up a voltage E_2 across L_2. If L_2 has more turns than L_1, the voltage E_2 will be greater than E_1.

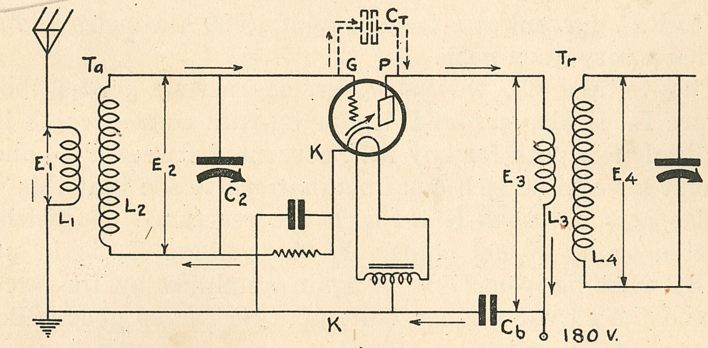

Fig. 1

Voltage E_2 is impressed across the grid (G); and the cathode (K), the grid return. The tube amplifies the voltage E_2 to μE_2 or the voltage E_3 which now exists across L_3 the primary of the R.F. transformer T_R. Again by mutual inductance E_3 is raised to E_4 to an extent determined by the turn ratio and the effective coupling between L_3 and L_4. The ratio of the voltages E_4 to E_2 (E_4/E_2) is what is often referred to as the voltage *gain* of the R.F. stage (R.F. gain). The ratio E_4/E_1 is the overall gain so far.

Although the tube amplification μ may be 8 for an ordinary UY-227 tube the voltage gain per stage is often less than 8 and less often more than 8 depending on design.

It would seem a very simple matter to have one tube stage follow another until enough gain is obtained to give the detector a strong signal. But it is not so simple. Regeneration in each stage largely determines how far this *cascading* of stages can be permitted. The other factors are: side band-cutting, which we already know about; and the mechanical problem of making condensers C_1-C_2-C_3-C_4, etc., exactly alike and perfectly balanced. In fact, the problems are many and difficult for the radio engineer.

What about regeneration, which was the stumbling block for the past few years before the advent of screen grid tubes? The trouble starts right inside the tube. The grid is quite close to the plate (see Fig. 2) and there should be no doubt that because of this mechanical layout there should be a capacity between the grid and the plate. There is, and every tube has a grid-plate capacity C_T (in Fig. 1) and in the case of UY-227 it is about 8 $\mu\mu$f. (8 micro-microfarads) (.000,000,000,008 farads). This seems very small and it is but it offers a path for radio frequency current. In fact, its reactance will be 20,000 ohms to R.F. current at a frequency of 1,000 kilocycles and so it provides a very good path.

The voltage E_3, we know, besides acting across the inductance L_3, is also across P-K, for by-pass condenser C_b is an exceedingly low path for any R.F. currents between P-L_3 and K. We don't have to stretch our imaginations to see that this voltage also acts across G-K through the reactance C_T which we estimated to be 20,000 ohms. If the voltage E_3 is in phase with E_2 what happens? It is again amplified by the vacuum tube and the signal further built up. So far so good. But if regeneration, for after all, this is regeneration, which we have already studied, is carried too far, the tube will oscillate and squealing will result.

At lower frequencies, that is, 550 kilocycles, the reactance of C_T will be high and at high frequencies, the reactance will be small. The result is that oscillation is more prevalent at high frequencies (low wavelengths) and hardly noticeable at low frequencies (high wavelengths). This also explains partially why ordinary radio frequency sets are more sensitive at high frequencies—because regeneration boosts a weak signal.

CORRECTING REGENERATION

When only one stage or radio frequency is employed there is not enough regeneration to be objectionable. The problem is

of vital importance when two, three or four stages of R.F. amplification are employed. Radio's development clearly shows that this problem was a difficult one to master. For some time only two stages of radio were possible and it has only been in recent years that the multi-R.F. receiver was successful.

In general it can be said that the larger the tube capacity (C_T); the greater the inductance L_3; and the greater the tube amplification;—the greater the tendency to oscillate. The capacity C_T is strictly more than just the tube capacity. It may include the capacity between wires leading to the grid and plate of the tube and there may even be capacity between the prongs of the tube or the contacts in the socket. These facts are of great importance to the serviceman.

Many valuable methods have been invented to overcome regeneration. And radio receiver performance has made great strides due to them. The methods are of extreme importance to

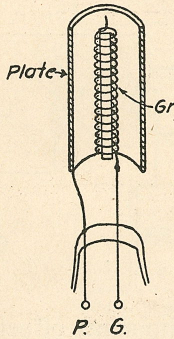

Fig. 2

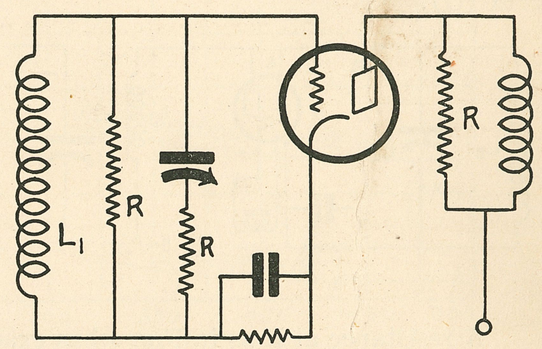

Fig. 3

Radio-Tricians as there are millions of such receivers in existence rendering perfect service but at times requiring adjustment. This is a very good reason for studying this phase of Radio.

The methods of *stabilization,* as elimination of R.F. oscillation is ordinarily called, may be divided into three main groups.

(1) Introduction of absorption to waste the regenerative power; by means of *lossers.*

(2) Counteracting the reactance of C_T; the method better known as *neutralization.* Sometimes this method is referred to as the *bridge* method.

(3) By reversing the phase of E_3 with respect to E_2 so that the signal cannot be reamplified.

LOSSER METHODS

A cheap Radio receiver or an old machine is an example of a complete losser system. For example the coils may be damp and covered with leaky material, the insulation may have spoiled, or the variable condensers may be leaky, or excessive metal may be near or inside the coils with the result that L_2, L_3 and L_4 as well as C_2 may be loaded with resistance and in that way prevent the flow of regenerative currents. See Fig. 3. Lossers of this type prevent oscillation, but their bad effects are worse than the regeneration. The selectivity and sensitivity of the machine are ruined.

The proper losser methods are shown in Figs. 4 and 5. Both these methods were explained before. In Fig. 4 the grid suppressor method is employed. As a losser means of stabilization it is without doubt the best method available and can be used in modern screen grid circuits directly next to the control grid (G).

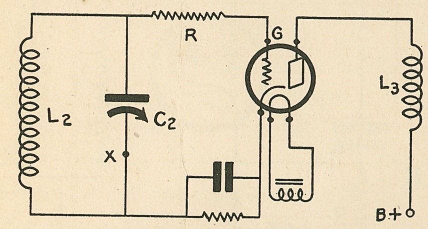

Fig. 4

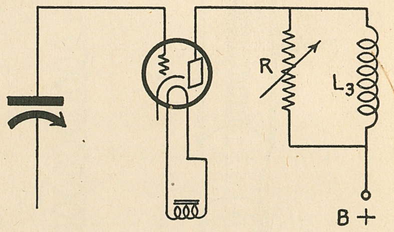

Fig. 5

A resistance at R as in Fig. 4 has exactly the same effect as a considerably smaller resistance at point X. A resistance at point X of 50 ohms is often more than sufficient to stop all oscillation at a high frequency. Although a resistance in the oscillatory circuit does affect selectivity and sensitivity, if it were just enough to prevent oscillation at each frequency between 1500 and 550 kilocycles, the method would be quite ideal. But a fixed resistance in the oscillatory circuit formed by L_2-C_2 reduces the strength of the incoming signal regardless of the frequency and therefore diminishes the regenerative feed back. The result is that a correct value of resistance at X to prevent oscillation at 1500 kc. will result in too much loss at 550 kilocycles and decreased amplification.

The resistance R used as a grid suppressor overcomes this fault. The resistance R is not in the resonant circuit. The current that passes through it depends on the reactance of C_T which

we have already learned becomes smaller as the frequency goes up. Thus a greater current will flow through R at higher frequencies, due to the feed-back just explained. Consequently the IR drop at 1500 kc. will be considerably greater than at 550 kc. and feed-back voltage will be less. We know that it is desirable to allow more regeneration at high wavelengths where it is needed and "choke" it at low wavelengths. In Fig. 6, the sharp curve A shows the IR drop in the suppressor plotted against the wavelength, the other curve B is an imaginary curve showing the effective regeneration plotted against wavelength. This latter curve might well be the sensitivity curve.

Note that a grid suppressor tends to even out amplification

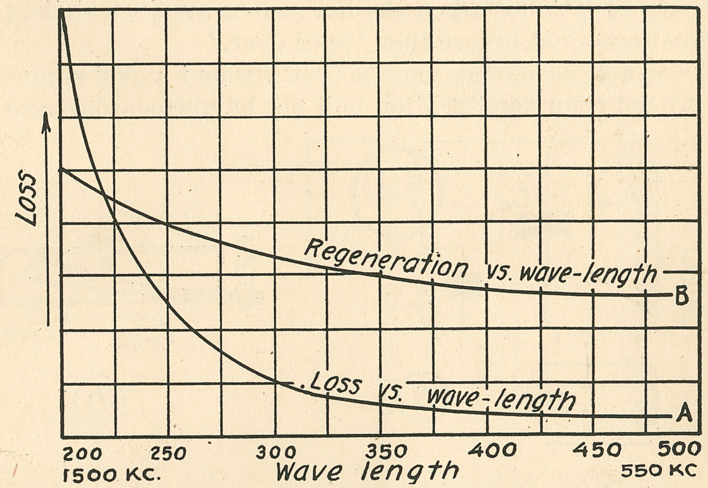

Fig. 6

over the complete scale of tuning, and so is a most desirable method of oscillation control. Usually a resistance of 500 to 1,000 ohms is quite sufficient. Where several R.F. stages are used it has been found practicable to use staggered values, thus 500^{ω}, 600^{ω} and 700^{ω} in the first, second and third R.F. grid circuits. Interchangeable suppressors are best, for then the proper values may be found by experiment. If a set using grid suppression has a tendency to oscillate, it may be kept from "spilling over" by using a larger grid suppressor. If a suppressor of 1200 ohms does not stop oscillation, the trouble is elsewhere (improper shielding; coupling between grid and plate leads; or too large a primary).

In actual practice, the smaller the grid suppressor the greater the regeneration and the more sensitive a receiver will

be. Of course there is always the danger of oscillation when smaller suppressors are used.

By using a variable resistance of 0-5,000 ohms in addition to the grid suppressor, connected across L_3 as in Fig. 5 an absolute means of controlling regeneration and volume at the same time may be had.

When this combined method of grid suppression and volume control is used, the resistance value of the suppressor should be such that when the variable resistance is at maximum, regeneration should be just barely perceptible at the lowest frequency. Then by decreasing the resistance of variable R any tendency to "spill over" at higher frequencies can be controlled. Maximum sensitivity is obtained when the R.F. tubes are just at the point of oscillation—just before they "spill over."

A variable resistance may be used without a grid suppressor (Fig. 5) but then amplification will not be uniform because this

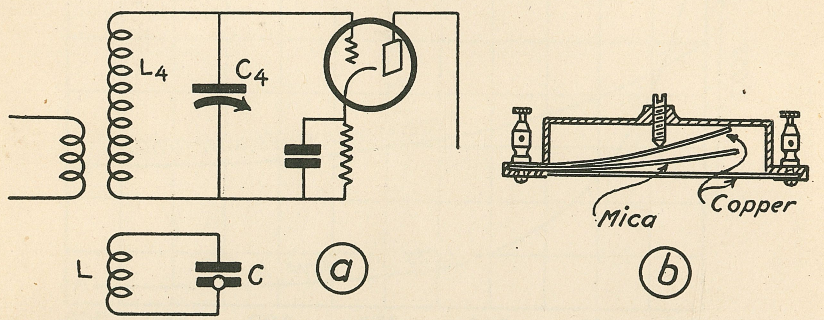

Fig. 7

method does not level out amplification as the grid suppressor does. The action of the variable R is as follows:—Because it is an extra load in the plate circuit, it lowers voltage E_3 (in Fig. 1). The lower this voltage is, the less e.m.f. there will be to push a current across the reactance of C_T. Thus regeneration and volume are controlled by controlling voltage E_3.

A method used at times is shown in Fig. 7a. A coil L, having from ¼ to ¾ as many turns as L_4, is wound on a small tubing just large enough to slip into the tubing of L_4. The wires of L are usually bunched so there will be no capacity between L_4 and L. An adjustable capacity C, constructed as in Fig. 7b, is connected across L. Its capacity is about ½ that of the maximum value of C_4. Capacity C and inductance L form an oscillatory circuit drawing its energy from L_4 by mutual induction. If the L-C circuit is tuned to the L_4-C_4 circuit is will absorb prac-

tically all the latter's energy, a condition quite undesirable. Usually L-C is tuned to the frequency at which the receiver "spills over" most and the adjustment made at a higher frequency. In this way a fair oscillation control is available. Of course C may be a variable condenser and tuned from the panel. In this way it may even be a sensitivity and volume control. However, this method is inferior to the grid suppressor method and furthermore has the disadvantage of upsetting tuning, a serious defect when condensers are ganged.

Another method of preventing oscillation is by bringing a copper or brass plate near the coil L_4, or putting a circular disc inside the tubing of L_4. See Fig. 8. The disc acts as if it had thousands of little circuits in which currents are created by

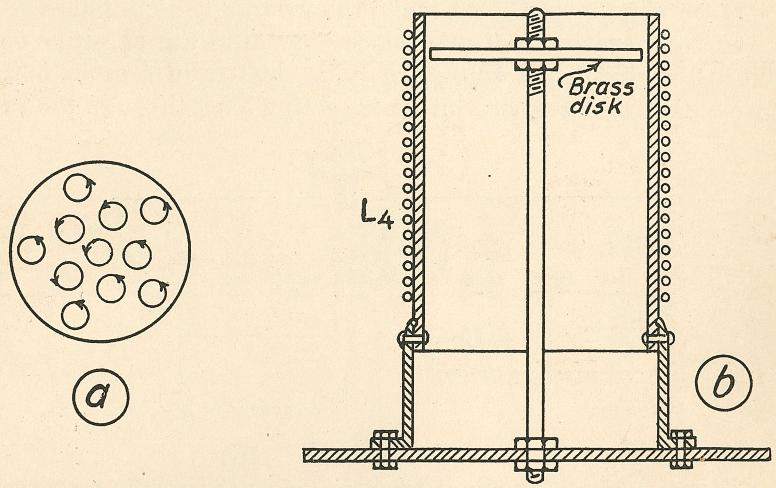

Fig. 8

mutual induction. The currents are larger at high frequencies. These miniature circuits have resistance and a loss takes place in the form of an I^2R loss. Clearly this method would tend to prevent excessive oscillation at high frequencies and likewise would have little effect at lower radio frequencies.

Some manufacturers arranged the disc so that it could be made to slide in and out and be controllable at the panel; others arranged the disc so that it could be rotated so as to uncover the coil, with identical results. This method has the disadvantage of affecting selectivity and sensitivity, but it is not serious if not carried too far below the point of oscillation. It also affects the inductance value of L_4 and for this reason a knob control of the disc is quite often used for *"vernier tuning."*

This method employs "eddy current" reaction, which is important in radio shielding, a subject we shall take up soon.

STABILIZATION THROUGH "PHASE SHIFTING"

A unique method of oscillation control once extensively used by set-builders and manufacturers was introduced by John F. Rider. It is both a phase shifting arrangement and a losser system. See Fig. 9. A condenser of about .002 mfd. is placed in the plate circuit of the oscillating tube in series with primary L_3. Of course this keeps the B supply from reaching the plate. A variable resistance R of 0-10,000 is connected between the plate and the 180-volt supply to provide a path for the plate current.

If the condenser C is shorted, the voltage E_3 is in phase with E_2 and regeneration will take place. By allowing capacity C to exist in the circuit the voltage of E_3 is shifted 90 degrees out of phase with E_2. Thus the voltage E_3 acting back through the tube

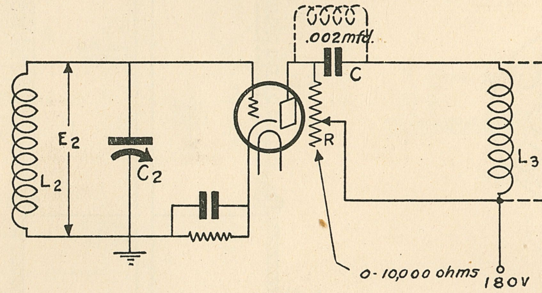

Fig. 9

capacity does not entirely aid E_2 and regeneration is materially reduced. A 180° phase shift would not only totally eliminate regeneration but decrease the signal and, therefore, is quite undesirable. Further decrease in regeneration may be accomplished by the losser action of R. This method although a good cure for stubborn squealing does not flatten the amplification of the receiver. However, by placing a coil of about 40 turns of No. 28 wire wound on a 1" tube across C, the phase shifting may be eliminated for high wavelengths and the lower band of frequency actually aided by regeneration.

SUPPRESSION OF OSCILLATION BY METHODS OF NEUTRALIZATION

Patent rights have limited the greatest number of manufacturers to the foregoing methods of regeneration control but

yet a considerable number use one form or another of *neutralization,* introduced by Prof. Hazeltine. In general, neutralization is accomplished by introducing into the grid circuit an e.m.f. just large enough to balance out that which may be introduced by regeneration or feed-back. Sometimes, this is referred to as eliminating the tube capacity but strictly speaking should be considered as counteracting tube reactance voltage drop.

Hazeltine Neutralization:

The tube capacity allows a voltage originating across the primary of the plate inductance to act back on the grid voltage in phase with it and in this manner strengthen the signal. Due to the impossibility of limiting this reverse action, violent oscillation may take place. Now the voltage across the secondary inductance is known to be 180° out of phase with the primary inductance. By tapping the secondary at a proper point, the

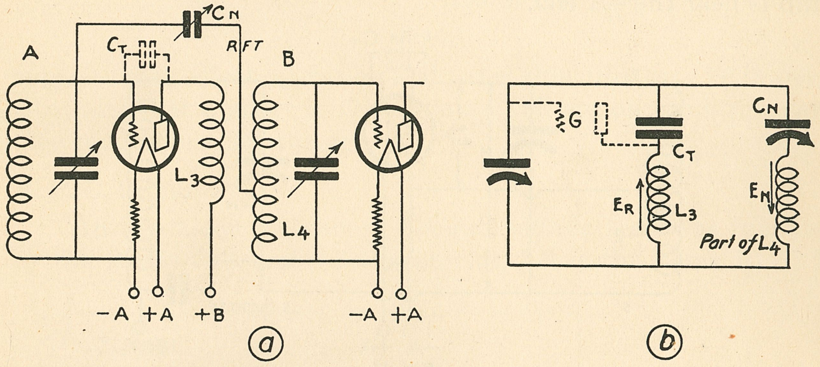

Fig. 10

voltage in the turns up to the tap is directed back to the grid through a midget vernier condenser.

Thus, in Fig. 10a, the R.F. transformer (L_3-L_4) supplies both the regeneration and the counter-e.m.f.'s. Terminals +B and –A of both primary and secondary are at the same potential when considering radio frequency current.

The voltage across the primary feeds the grid with an "in-phase" voltage through C_T, whereas the voltage across the tap on the secondary and terminal –A feeds to the grid a voltage out of phase with the first voltage. By proper placement of the tap and by using the correct size of neutralizing condenser C_N, the neutralizing voltage can be made to balance out any tendency to oscillate. Fig. 10b will make this clear.

The position of the tap on L_4 may be approximately calculated. If inductance L_3 has N_R turns, the proper position of the tap will be approximately given by the following formula:

$$N_N = N_R \times \frac{C_T}{C_N}$$

where N_N is the number of L_4 turns up to the tap.

Strictly speaking, if there were no capacity between the coils L_3 and L_4 when the condenser C_N was adjusted, oscillation would not occur at any frequency. However, the effective inductance of L_3 and L_4 does decrease with increased frequency and the voltage of neutralization is not 180° out of phase. Also capacity between L_3 and L_4 will vary with frequency and upset a definite setting. An approximate adjustment only is possible. It is quite essential that L_3 and L_4 be connected to the tube in such a manner that opposite voltages are present. Usually the tap is near the –A end.

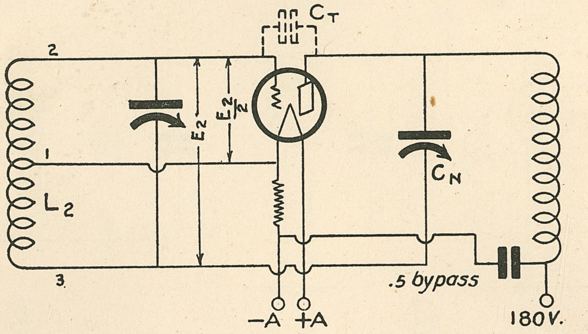

Fig. 11

Rice Method of Neutralization:

Another neutralization method that has, however, commercial draw-backs, is the Rice method. The inductance L_2 (Fig. 11) feeding the grid of the oscillating tube is center-tapped and connected to the cathode (filament). Naturally, the center of the coil L_2 becomes zero potential, that is, it is at A– or ground potential. The upper end is connected to the grid and the lower end, through the neutralizing condenser, to the plate. The capacity of the neutralizing condenser is equal to the tube capacity. The voltage across 1-2 is 180° out of phase with voltage across 2-3. Thus, any regenerative voltage fed back to the grid is exactly balanced by an equal and opposite voltage. Any deviation from a condition of voltage balance will cause oscillation.

The disadvantages of this method are: that only half gain is obtained as the grid voltage instead of being E_2 as in Fig. 1 is now $\frac{E_2}{2}$, for only the voltage between 1 and 2 results in tube amplification; that ordinary ganged condensers cannot be used as the stator is connected to the plate through C_N; that body

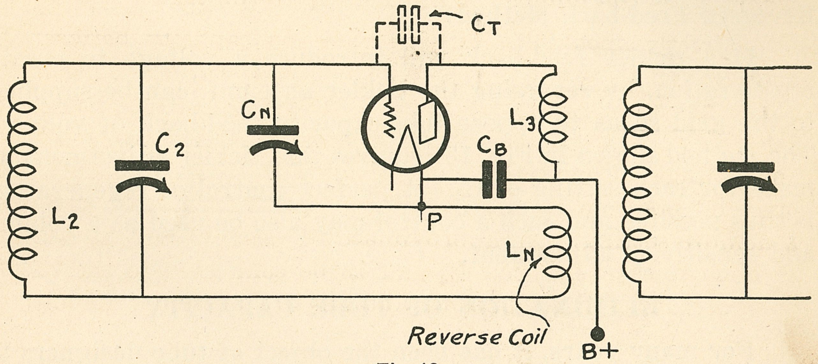

Fig. 12

capacity may affect operation and panel shielding may be imperative; and that a short in C_N throws a voltage on the large variable condensers and the grid.

R. F. L. Circuit:

An ingenious method of reverse voltage feed was invented by the Radio Frequency Laboratories, hence the name R. F. L.

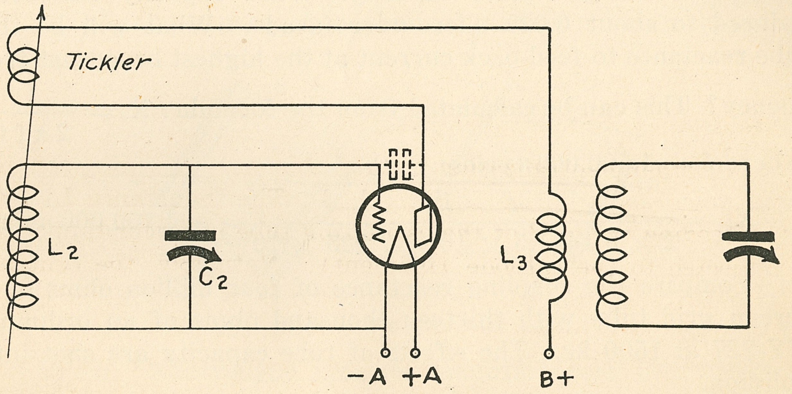

Fig. 13

circuit. A coil of a few turns, L_N in Fig. 12, is connected by mutual induction to L_3 and may be made to create a voltage either to aid or oppose oscillation. By connecting it to the grid through a neutralizing condenser C_N a counter-e.m.f. can be

applied to the grid to wipe out regeneration. Capacity C_N is much larger than the tube capacity C_T. A contact between L_N and C_N is made with cathode at P. This connection, however, may be eliminated without any change in operation, and this is usually done in A.C. receivers. C_B is a large by-pass condenser (.5 mfd.).

Reversed Feed-back Method:

If a tickler feed-back will introduce a voltage to create regeneration, by reversing the tickler an e.m.f. can be supplied to the grid so as to oppose tube-capacity feed-back of voltage. The method shown in Fig. 13 requires that tickler adjustment be made for each setting of C_2. A perfect control of regeneration is thus possible and such a control may also be used as a volume and sensitivity adjustment.

ELIMINATION OF TUBE CAPACITY

For many years, it has been the object of tube designers to develop three element (triode) tubes having extremely low tube capacity. Eight micro-microfarads for a UY-227 seems to be the lowest feasible capacity without affecting tube characteristics. The introduction of screen grid tubes revolutionized radio frequency circuits and banished the problem of feed-back stabilization necessitated by tube capacity.

The screen grid tube has been studied, but what interests us now is the grid-plate capacity. Tube capacity has been reduced to about 0.025 micro-microfarads. What will be the tube reactance to feed-back current at the highest broadcast frequency? This can be calculated from the formula: $X_c = \frac{1}{2\pi f C}$.

Where f = 1,500,000 cycles:

$$X_c = \frac{1}{2 \times 3.14 (1.5 \times 10^6) \times .025 \times 10^{-12}} = 4{,}150{,}000 \text{ ohms.}$$

Compare the coupling reactance of four million ohms of a screen grid tube with thirteen thousand ohms of an ordinary UY-227 at 1500 kc. The effects of tube capacity are shot into oblivion.

ELIMINATION OF MAGNETIC STAGE COUPLING

Capacity between tube prongs, socket contacts, grid and plate leads, is of extreme importance. Unless precautions are taken, the low internal capacity of the screen grid tube is

destroyed. Feed-back between coils of adjacent stages is now the chief cause of screen grid oscillation. It is a problem in the three-element tube, but a much more serious consideration in the four element tube circuits.

An inductance to be efficient and have low resistance with maximum inductance, is made in such proportion that the diameter of the coil winding is approximately equal to its length.

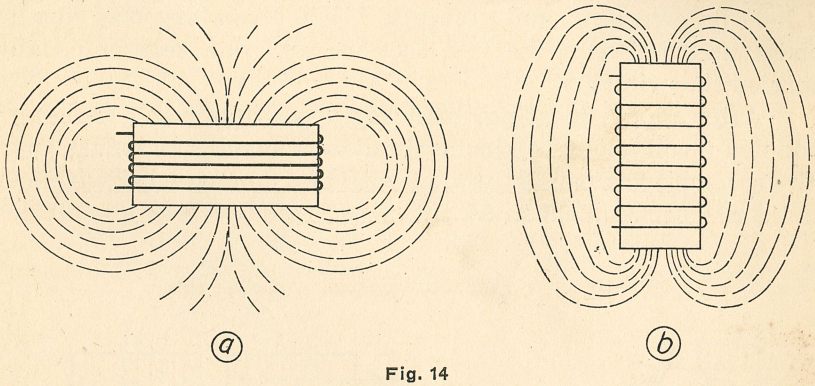

Fig. 14

Unfortunately, such coils have magnetic fields that spread quite a distance from their sides. In Fig. 14a, the field about a short coil is shown. The coil in 14b, designed much longer, has its field close to the sides.

In the early days of neutrodyne circuits, coils were usually designed so they were 2½ inches in diameter and 2 inches long. Placing of coils to prevent magnetic induction between them was

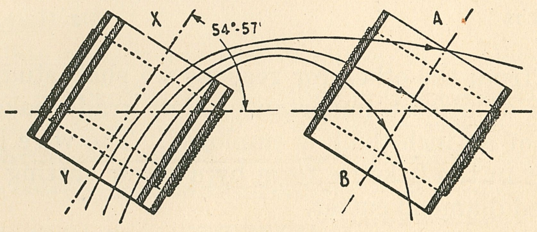

Fig. 15

a problem. Neutrodyne receiver manufacturers used the coil placement arrangement shown in Fig. 15. The angle D was about 55°, but no hard and fast rule could be set. Too much depended on coil size and placement.

Many schemes were used to prevent stray fields. The one shown in Fig. 16, proved quite effective. The coil, including pri-

mary and secondary, was wound in the shape of a doughnut, the field existing inside. Little leakage took place. However, it was by no means easy to make this kind of coil so that it would match ganged condensers.

A double coil arrangement as in Fig. 17, was the outcome of the ring (toroidal) coil. It approximated the effect of the latter and allowed substantial and precise construction. In fact, it held its own until quite recently. The secondary was equally distributed between the two sections and one section usually carried the primary.

After much debating, manufacturers and radio designers adopted a coil about 1¼ inches in diameter and 1¾ inches long. The secondary is usually wound with No. 30 enameled wire and there are between 60 to 90 turns per inch. Wires are always

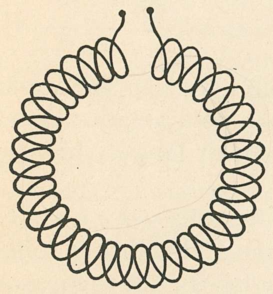

Fig. 16

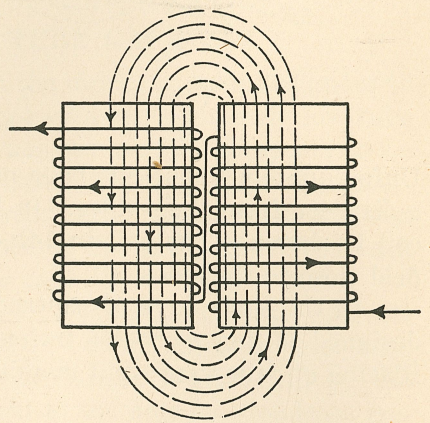

Fig. 17

spaced one from the other for reasons we shall study soon. As precision is of utmost importance, high grade bakelite tubing about 3/32 of an inch thick is employed. The wire is wound on a thread cut in the bakelite form by a screw cutting lathe using a "V" shaped diamond cutter.

In spite of variations in tubing diameter, this last process makes all tubing exactly alike. A total of nearly 120 turns is generally used. Not all coil windings are like this, but in general, they are. Some manufacturers dry their coils in a furnace and dip them in moisture-proof wax of low dielectric capacity having high insulation resistance. Such a coil is shown in Fig. 8, except that the damping disc is not used in modern circuits.

This coil, being longer than wide, has a restricted side flux and so when several are used, they are usually placed perpendicular to each other as in Fig. 18. What flux does cut the wires of adjacent coils does not link with them because it does not cut the wires at right angles. Thus, whatever effect there is between coils is very weak. When the gain per stage is low, this coil arrangement possesses low *inter-stage* coupling and serves well as a coil layout.

Besides the fact that it is not possible to space coils to prevent magnetic coupling between stages altogether, there is another serious drawback to "open coils," which has caused their total disappearance in the modern receiver. You may have noticed that an old type receiver with open coils will pick up stations 50 to 100 miles away with the aerial and ground disconnected. This is because the open coils acted as small antennas. Of course a receiver that will do this is inefficient—it

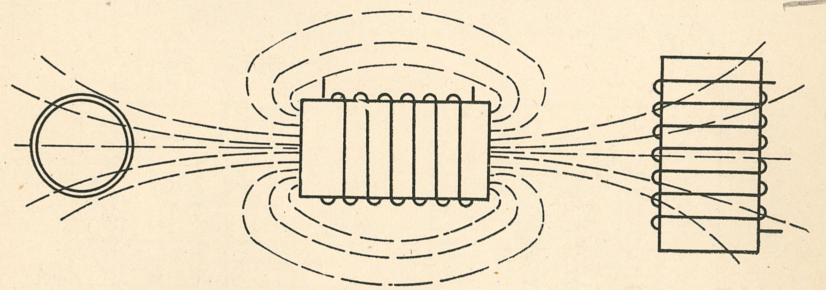

Fig. 18

lacks selectivity. If used near a powerful local station is will resonate to (tune) the local over 10 to 50 out of 100 divisions on the tuning dial.

A possible remedy for this condition is to place the entire receiver in a metal box and so "shield" the receiver. Then no parts in the receiver can receive signals except through the antenna system. Of course, this does not shield one part from another—it merely shields the receiver as a whole.

SHIELDING

So much importance is attached today to shielding that the underlying principles and use of shielding must be thoroughly understood by Radio-Tricians.

We begin our study of shielding with a simple radio coil. Let's assume that it is connected to a supply of A.C. voltage, resulting in a flow of current through the coil whose inductance (L) is, let us say 250 microhenrys. A magnetic field is built up

about the coil whose lines of force (flux, F) flow first in one direction then in the other, in phase with the reversal in direction of the current within the coil. See Fig. 19.

If the source of e.m.f. were a battery, that is direct current, the magnetic lines of force would always be in one direction, and the flux near AB would extend out in both directions as far as it could reach. Now if a plate (S), made of copper, aluminum, bakelite or glass were placed near the coil, an instrument (X) to detect magnetic flux would show that flux actually goes through the plate and that the amount is the same whether glass, bakelite, copper or aluminum is used. These are non-magnetic materials, that is, they do not conduct magnetic lines of force. But an iron plate at S would prevent any flux from getting through because iron conducts flux and bends the lines F so as to conduct them along the plate.

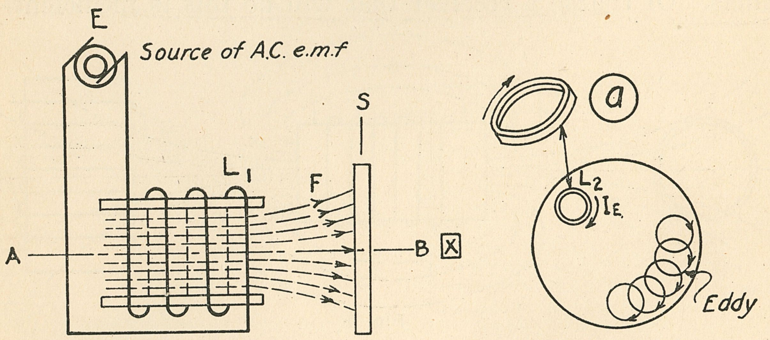

Fig. 19

Now let's see what happens when an A.C. generator is used, assuming that the effective current is the same as in the previous D.C. experiment. If the current were a 60-cycle current the magnetic flux indicator would show that practically the same amount of flux was passing through plate S but if the frequency were increased from 60 to 500, to 10,000, to 100,000 to 500,000 cycles per second, always keeping the current constant we would find that indicator X shows less and less flux passing through a copper or aluminum plate. This same experimental set-up would show that if glass or bakelite were used, the same amount of flux would pass through constantly. It would not be affected by an increase in frequency. A simpler experiment to prove this same effect of frequency is set up in Fig. 20. Coil L_1 is placed near another coil L_2 and an A.C. voltage E_1 is placed across the terminals of L_1. An A.C. voltmeter placed across the terminals of L_2 would

read a voltage E_2—because our two coils are nothing more than an air core transformer.

A glass or bakelite plate S between coils L_1 and L_2 would not change the voltmeter reading of E_2—however, the insertion of a copper or aluminum plate causes the voltage E_2 to drop and if it is possible to increase the frequency of E_1 sufficiently, the voltage E_2 can be reduced to zero.

How can this be explained? We shall have to believe what most Radio engineers accept as the correct explanation—and to understand their explanation we shall have to use our imaginations. Within the plate S there are hundreds of little circuits, all jumbled together, but for the sake of simplicity we shall assume that a single one of these tiny circuits looks like L_2 in Fig. 19-A —just a small electrical ring. Each of the many electrical rings, L_2, acts as a secondary coil to L_1. From our study of transformers we know that an e.m.f. is induced in the ring L_2. But coil L_2 is short circuited and a current I_e flows first in one direc-

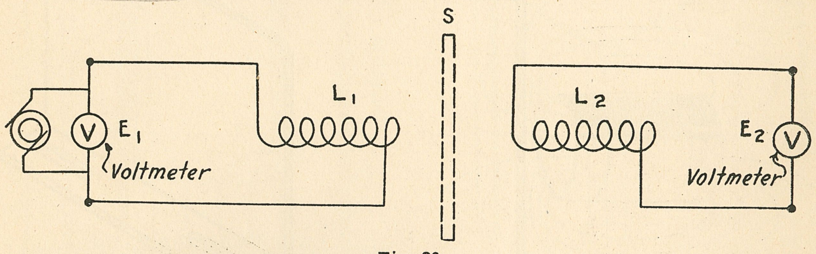

Fig. 20

tion then in the other according to flux changes. This current is called an *eddy current* because its action and flow can be compared with an eddy in a lake or river.

This changing current in L_2 has several effects which are of importance to us. L_2 has resistance besides its one turn of inductance and so power is lost in heat ($I^2_e R_e$). This power loss is called an eddy current loss. Of course it cannot be measured by measuring R_e and I_e—it is impossible to isolate a single eddy current and measure it. But the power supplied by the generator can be measured by a wattmeter (an electrical device to measure power in watts), and if the power is measured before and after plate S is inserted, the difference in reading will indicate the power lost in eddy currents. If this power is divided by the square of the current in L_1 the effective eddy current resistance of coil L_2 will be known ($R_e = \frac{P_e}{I^2}$). This resistance can

be added to the ohmic resistance of coil L_1 for the total radio frequency resistance.

It must be explained that even without plate S there may be eddy current loss. Eddy currents will be induced in some adjacent turns of the wire of L_1 by flux leakage. Of course there is resistance present in these small circuits and this resistance increases at higher frequencies—it will be greater at 1500 kilocycles than at 500 kilocycles.

Now, whether you realized it or not, we have been studying "shielding" about which so much is heard in connection with the latest receivers. Plate S is nothing more than a shield—but strange as it may seem, we have so far been considering only the detrimental effects of shielding. Eddy current loss is undesirable. Proper shielding must be able to deflect flux but eddy

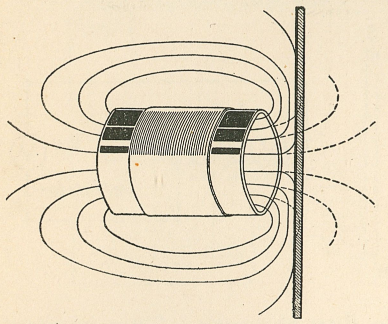

Fig. 21

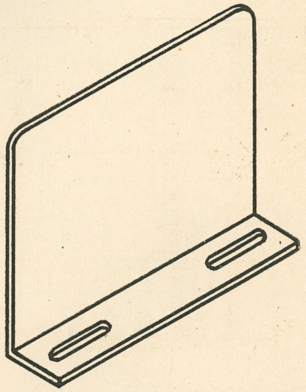

Fig. 22

current loss must not be large enough to affect selectivity. So far we have learned that the magnetic shielding properties of copper and aluminum increase with frequency and for this reason shielding is always made of either one or the other. Now we can go on and learn why eddy current loss in shielding is not large enough to affect the operation of a receiver.

Copper and aluminum have low resistivity. Comparatively large eddy currents can exist in them without much power lost in heat due to low resistance. Iron, lead, tin and brass have a much higher resistivity, consequently power loss would be high if they were used for shielding.

But, as said before, the idea is to get maximum shielding with minimum loss. The action of the minute coil L_2 as an electromagnet has a great deal to do with efficient shielding.

The current flowing in L_2 sets up its own flux in a direction opposite to F. Then whatever flux is not reduced in its attempt to get through S is bent away from plate S as in Fig. 21. However, if the plate is too thin some flux may get through, and for this reason shielding is made as thick as possible and convenient—between 1/32 and 3/32 of an inch.

If the frequency of reversals of the flux direction is increased without changing the flux strength, the voltage induced in L_2 will increase, and with it the current. The result is more effective shielding but at the cost of increased eddy current loss.

An aluminum or copper plate (Fig. 22) may be used between coils or parts in a Radio receiver but more often the coil

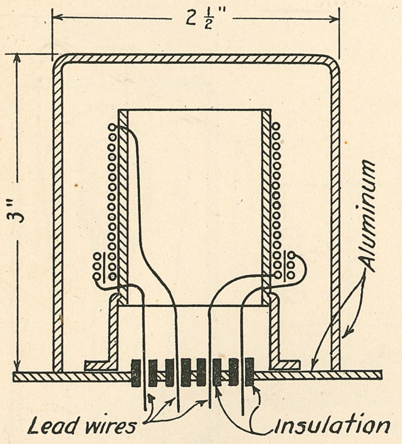

Fig. 23

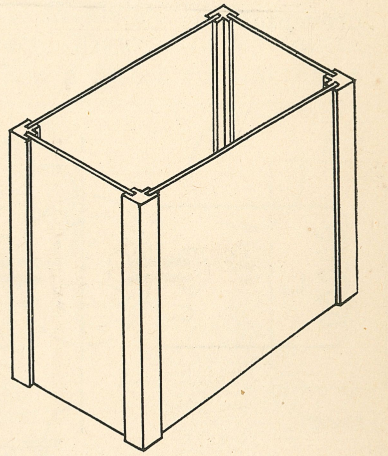

Fig. 24

itself is placed in an inverted aluminum or copper can, as in Fig. 23. It is important that the shield be not too close to the coil or its inductance will be reduced considerably and eddy current losses will be large enough to reduce selectivity. Modern coils are small and built longer than wide, so that a distance of ¾ of an inch between the coil and the shielding is considered ample.

In quality receivers, especially in the latest screen grid receivers where perfect isolation of one R.F. stage from the others is of the greatest importance, each R.F. stage is placed in a separate aluminum or copper box as in Fig. 24. This includes not only the coil, but the variable condenser, the R.F. choke, the by-pass and the tube. Wherever still more effective shielding is desired, the coil is shielded as a unit within the box.

Before we drop the problem of shielding, we must understand shielding of electrostatic fields as well as shielding of electromagnetic fields. Figure 25 shows two coils L_1 and L_2 in metal containers and so shielded from each other. If the cans are thick enough, there will be no electromagnetic interaction between them. We must not overlook the fact that condenser C_1 is charged and that its field, although mainly between the plates, may spread as shown and actually act between the plates of C_2. As condenser C_1 is being charged and discharged, its field is fed into C_2 and so circuit 2 will be coupled to circuit I. A current will flow in circuit 2 induced by this field. By placing a grounded metallic plate between condensers C_1 and C_2 the electrostatic lines of force can be diverted to the ground and coupling prevented.

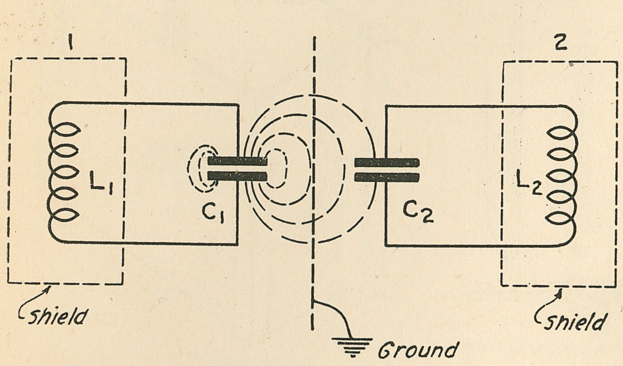

Fig. 25

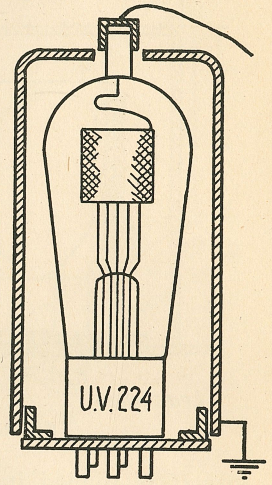

Fig. 26

Each variable condenser (and each section in a ganged condenser) is separated from the others by a grounded metal plate. Coils must be shielded one from the other for the same reason. By placing regular electromagnetic shields at ground or B– potential they will also act as electrostatic shields. Screen grid tubes which have very large internal elements are quite often separately shielded, as in Fig. 26, if not placed within a metal box with their other stage components.

R. F. COIL PROBLEMS—HIGH FREQUENCY RESISTANCE

From our study of resonance and selectivity, we know that if a radio frequency coil has too high resistance, the tuning

within that stage will be broad and the sensitivity of the Radio reduced. A single layer coil made of No. 28 D.C.C. (double cotton covered) wire wound on a 3-inch tubing with an inductance of 300 microhenries (60 turns of wire) will have a resistance of approximately 3 ohms when direct current is flowing; a resistance of 6 ohms with an A.C. current of 500 kilocycles; 10 ohms at 1000 kc.; and 15 ohms at 1500 kilocycles.

Part of this increase in resistance is due to the eddy current loss as already explained. The use of No. 24, or larger, No. 18, wire would increase the A.C. resistance faster at high frequencies than wires above No. 24. Consequently, small wires are just as good as large wires for Radio work even though the direct current resistance is higher.

Another factor which contributes to higher frequency resistance is what is known as *skin effect*. Figure 27a represents a cross section of copper wire. When a direct current flows

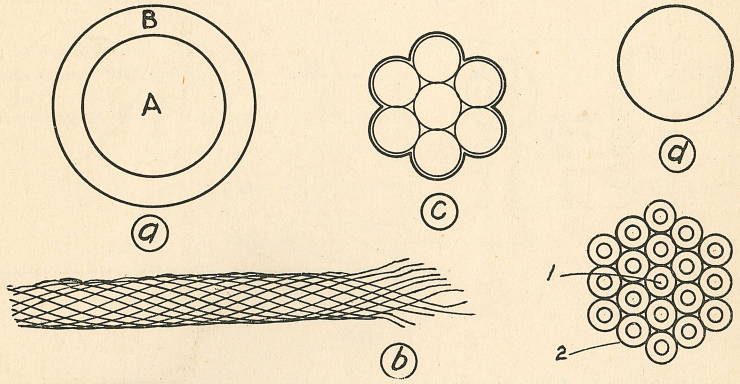

Fig. 27

through it, the current passes through every portion, both the center A and the outer surface B. But at very high frequencies an action takes place at A quite similar to eddy current action, preventing a current from flowing through that portion. As a result, the current flows mainly at the surface of the wire (B). We know that as the area of B is decreased the resistance goes up. This is, in effect, an increase in wire resistance and is appreciable at high radio frequencies.

In broadcasting stations or telegraphic stations, "copperclad" wire may be used, that is, the center A is steel, the surface B is copper. Thus a stronger and cheaper wire is had.

A reduction of this skin effect is accomplished by braiding or twisting together a number of small wires. Thus the eddy cur-

rent effect may be broken up and larger external areas for the high frequency current made available. See Figs. 27c and d. In weight, c and d are alike, but note the increase in surface area. The wire in 27c is called *stranded wire.*

The wire shown in Fig. 27b is LITZ (Litzendraht) wire. This is a special stranded wire made up of a large number of small wires, each of which is enamel covered and so insulated from the others. The strands are woven in such a way that each separate strand is on the surface of the wire for the same proportion of the total length as every other strand. Otherwise, the conductive effect would be destroyed—the same amount of current must flow in each strand.

The advantages of Litz wire are: uniform increase in resistance at increasing frequencies; comparatively small eddy current losses between turns, for they are insulated from one another. The disadvantages are that a single broken strand

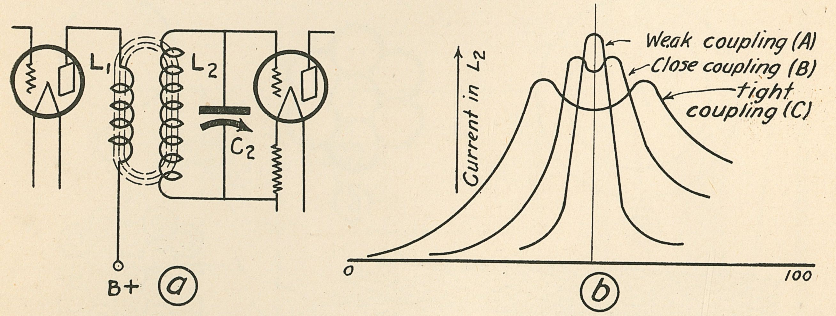

Fig. 28

seriously affects the conductance of the coil in which it is used and that connections to the circuit are difficult to make because of the enamel insulation—it may take as long as an hour to clean the ends for a perfect connection. Because of these disadvantages, Litz wire is not commonly used in commercial receivers. It is used, however, in some custom-built receivers. When used, only the secondaries of the R.F. coils are wound with it. Litz wire may also be used in transmitters along with strip copper or copper tubing.

RADIO FREQUENCY COUPLINGS

So far we have considered only the actual tuning inductance, the secondary, but the actual coupling between the plate of the R.F. tube and the grid of the following R.F. tube has a most important effect on a set's operation.

The most common method of coupling the plate and grid is through a radio frequency transformer, having a secondary tuned by a variable condenser. See Fig. 28a. The secondary inductance is calculated from the formula, $f = \frac{1}{2\pi\sqrt{LC}}$ to match a variable condenser of .00035 or .0005 microfarads, both standard values for Radio receivers. Usually, the smaller condenser is used because it is inexpensive and because a greater voltage may be impressed on the grid (the smaller the capacity, the greater will be the number of turns on the secondary inductance).

Design and position of the primary are by no means easy and as in all engineering procedure, a compromise between advantages and disadvantages is necessary. Let us review what we studied in R.F. tuners in the earlier part of the course. Remember that as the coupling between the primary and the secondary is increased, the tuning becomes broader.

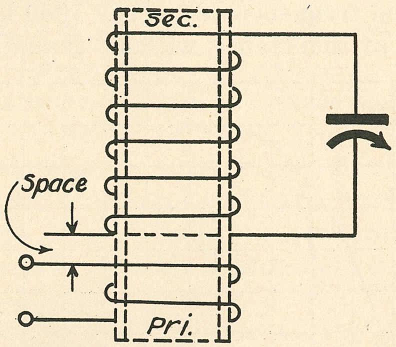

Fig. 29

The primary turns may be wound over the secondary separated from it, of course, by insulation material, or the primary may be wound on bakelite tubing and slipped inside the secondary. For low capacity between primary and secondary, the primary would be wound with very fine wire (its resistance compared to the plate impedance would be negligible) with windings bunched. Where capacity is not of importance, the primary winding is usually spaced to cover the entire secondary. These represent tight coupling positions and the coupling becomes greater as more turns are added to the primary. By concentrating the primary turns and placing them on the same tubing but spaced away as in Fig. 29, the coupling will be made weak. The greater the space between primary and secondary, the weaker the coupling. If the primary turns are increased, the space must be in-

creased to keep the coupling constant. In this way, too, various degrees of coupling may be obtained.

Coupling affects two important characteristics of a Radio—first, selectivity and secondly, the amount of current in the secondary circuit. Figure 28b, curve A, shows the variation in current in the secondary as the variable condenser is turned. It appears as a very steep sharp curve, and denotes a very selective receiver. Sharpness of tuning may be stated in a formula—

$$\text{Sharpness of resonance} = \frac{L\omega}{R}$$

where L is the apparent inductance* of the secondary coil.
ω is 2×3.14 multiplied by the frequency
R is the high frequency resistance of the coil.

For any fixed frequency, let us say 1000 kilocycles, increasing the amount of inductance without changing the resistance

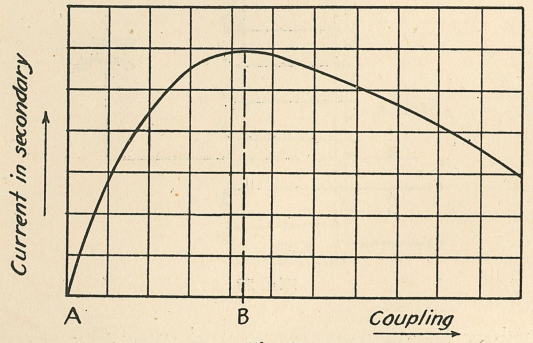

Fig. 30

loss would make a set tune sharper. Of course, this is impossible for as we put on more turns of wire, the resistance goes up rapidly. Likewise, decreasing R the resistance of the coil by better design in construction will increase the selectivity. Most engineers devote their greatest effort to making the high frequency resistance of a coil as low as possible. It would appear that as the frequency is increased, that is, from 550 to 1500 kilocycles, sharpness of tuning would become greater. Here we must not overlook the fact that the resistance is going up by leaps and bounds and is quite large at high frequencies.

*See Reference Book "Inductance."

As coupling is increased, the variable condenser seems to hold (tune) the station at more divisions of the scale. See Fig. 28b, curves B and C. And if the coupling is very tight, the station will be tuned in at two dial positions. From this it is evident that weak coupling is essential for selective operation.

How about sensitivity? For sensitivity, the current in the secondary should be large. (The voltage fed to the grid is $2\pi f L \times I_2$, where I_2 is the secondary current.) Figure 31 shows that as the coupling is increased from zero, the current in the secondary increases to a maximum value and any further increase in coupling will decrease the secondary current. Therefore, for maximum sensitivity, the coupling should be at B and for selective operation as near Zero (A in Fig. 30) as possible. The engineer must choose a method of coupling between A and B, depending on his problems, whether he is designing a receiver for selectivity or sensitivity or both.

Every engineer has another problem, the best point of operation for a vacuum tube. The plate current will be the greatest when the internal tube impedance equals the load impedance, in this case the impedance of the primary of the R.F. coil. To make it large requires more turns, increasing the coupling and thereby affecting selectivity. Furthermore, a large primary inductance means a large voltage across it which feeds back through the tube capacity and results in oscillation. So you can see that proper coupling is a difficult problem, an apparently unsolvable problem, one of the reasons why the perfect receiver has not been and seemingly cannot be built. In the case of the screen grid tube, the plate impedance is so large that it is not possible to come anywhere near a proper balance, and the maximum amplification of the tube cannot be realized.

But for the screen grid tube as an R.F. amplifier, our discussion of tube-to-tube coupling might well have stopped here. The importance of matching the screen grid plate impedance with the load impedance for maximum gain per stage has brought up many problems and many solutions have been suggested and tried. As many methods are available as there are methods for the neutralization of regeneration. A correct solution is difficult for the engineer and to understand the problem of design is too complicated even for an advanced student. Let it suffice for us to know what the methods are and become familiar with those in common use.

The R.F. transformer we have been talking about so far is illustrated in Fig. 31a. It is shown in detail, with all chokes, by-passes and grid bias included. We need add little more except that a volume control may be had by any of the usual methods, with the double resistor method in most common use today; that is, a potentiometer to control the 75^{V} tap down to zero potential and at the same time increase R to maintain constant grid bias. The plate impedance is never matched to that of the load.

The method for matching impedance shown in 31b has been used extensively. A plate resistor of 250,000 to 500,000 ohms is placed in the plate circuit to match the 400,000 ohms of UY-224 plate impedance. In order to place 180 volts on the tube using 400,000 as the load resistance, an additional 1600 volts would be required. Only 250 is available in a commercial receiver. To use higher voltages would be beyond commercial possibilities. The tube, therefore, works far below peak efficiency. The load resistance is coupled through a .00025 mfd. condenser to the resonant circuit shown in bold lines. The connection may be to the grid for maximum coupling or to a tap shown in dotted line for less coupling.

By far the most universally used method today is that drawn in 31c. A choke of 85 millihenries replaces the high resistance and a plate reactance of approximately 500,000 ohms is obtained at high frequencies while only a few ohms resistance is offered to the D.C. plate current. This method requires exceptional care in shielding, otherwise regeneration will take place. In fact, it is generally impossible to connect the coupling condenser to the following grid but it is connected to a point more than half-way down on the tuning inductance. A gain of 70-80 per stage is common with this arrangement. The coupling condenser serves also to keep the 180 volts off the grid. It serves the same purpose in methods b, c, d and e.

It is known that a parallel resonant circuit (an inductance shunted by a capacity) has a very large reactance at resonance. By placing such a circuit in the plate circuit as in Fig. 31d, the plate impedance is approached without offering resistance to D.C. plate current flow. This direct tuned plate circuit will cause regeneration even in screen grid tubes. The coupling is so high that selectivity is greatly impaired. As a method of matching impedance, it is losing favor.

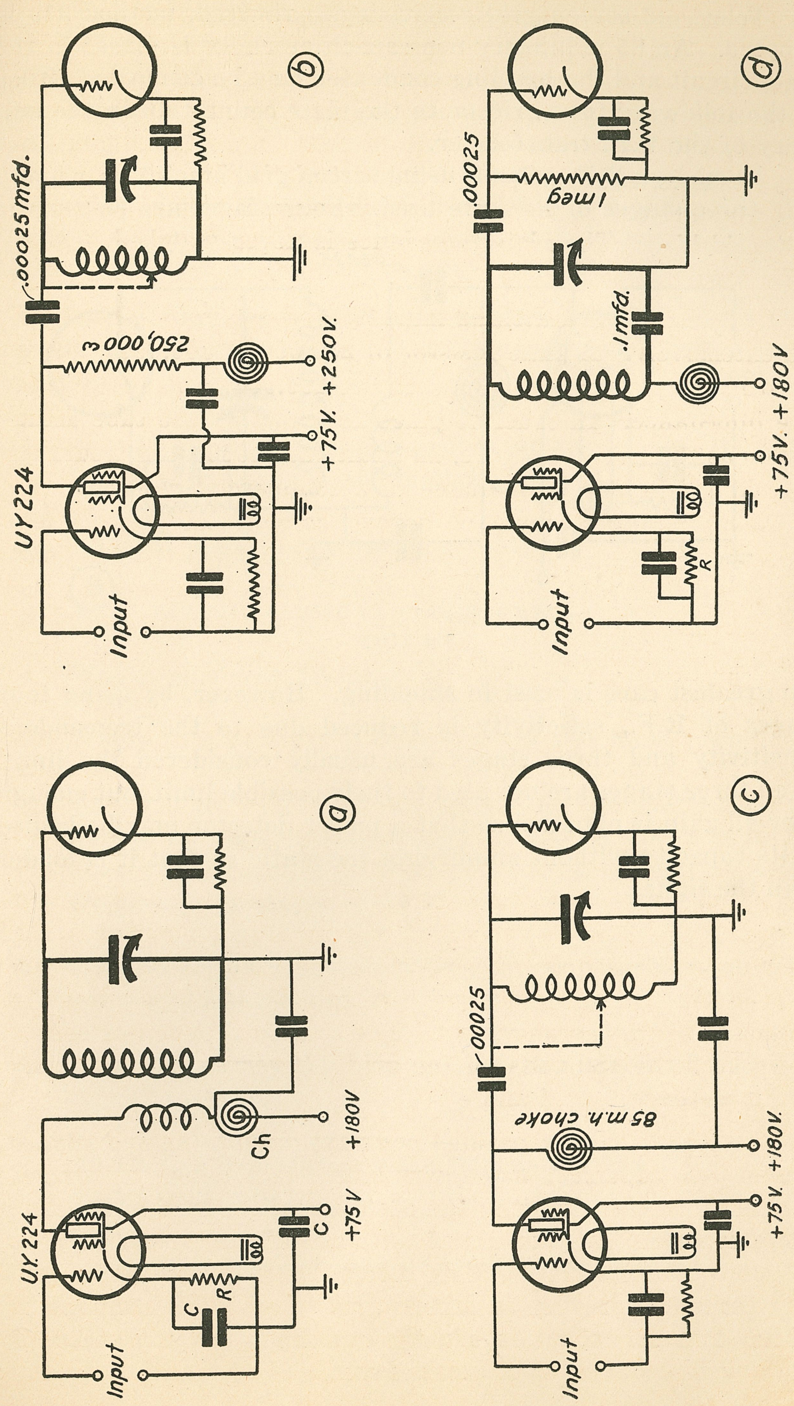

Fig. 31 (a), (b), (c), (d)

When old screen grid receivers are rewired, method 31e is adopted. An 85 millihenry non-capacitive choke is placed in the plate circuit and the coupling condenser may be connected either to the following tube grid or to the plate connection in the primary of the R.F. transformer.

In modern R.F. systems using screen grid amplifiers, usually only three stages of R.F. are used. Four stages are possible if

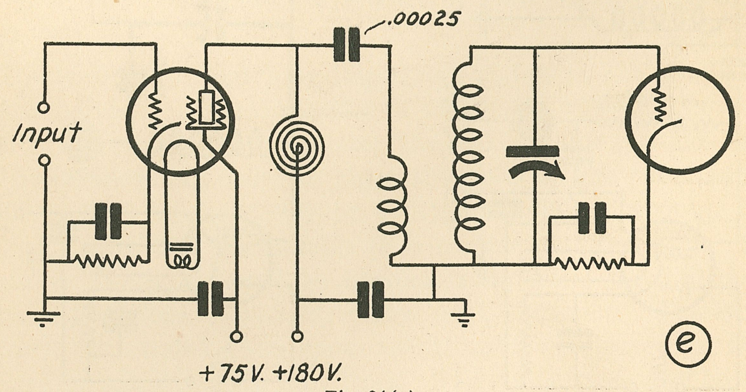

Fig. 31(e)

the greatest care is used in shielding. However, by using four stages of R.F., selectivity is reduced due to the tremendous sensitivity and three stages are usually considered the limit. Even three stages are not used to their possible limit, but enough over-all gain is obtained so that a power detector may be loaded to its capacity without amplifying the static so that it is louder than the signal.

TEST QUESTIONS

Number your Answer Sheet 20FR and add your *STUDENT NUMBER.*

Never hold up one set of lesson answers until you have another set ready to send in. Send each lesson in by itself before you start on the next lesson.

In that way we will be able to work together much more closely, you'll get more out of your course, and better lesson service.

1. (a) Explain the use of a grid suppressor. (b) Why is it better than other losser methods?

2. To what point is regeneration valuable?

3. What are two causes of oscillation?

4. Why is shielding necessary?

5. Where in a receiver is eddy current loss most prominent?

6. At 1,000 kc. which of these coils will tune sharper—a coil having an apparent inductance of 200 μh and a high frequency resistance of 15 ohms or a 350 μh coil having a high frequency resistance of 17^{ω}?

7. What effect do weak and tight R.F. coupling have on selectivity and sensitivity?

8. Show by a diagram the commonest method of matching plate impedance.

9. Which has the higher plate impedance, the triode or the screen grid tube?

10. In general, what is done to prevent R.F. oscillation?